

HGV CAB STRENGTH

James Anderson

Cranfield Impact Centre Ltd.
UK

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ABSTRACT

Currently in Europe there is no required legislation concerning the strength of HGV cabs in order to protect the occupants during a crash. Although some regulations and standards exist these have not been developed in a comprehensive manner to address typical real world accidents.

Through a three year project, that included accident investigation, computer simulations and cab testing, a new standard has been proposed for improving HGV cab strength.

A pendulum impact test addresses the frontal impact accident types and a quasi-static oblique roof crush test addresses the rollover accidents. Each test used a 95%ile Hybrid III dummy to define the occupant residual space.

The proposed standard will potentially form the basis of future European legislation regarding HGV cab safety.

INTRODUCTION

In relative terms, occupant safety in HGV's is good. Usually the HGV has the higher mass during a vehicle-to-vehicle collision and so is subject to lower decelerations. In addition the HGV cab occupants are generally above the impact region. However, when the impacted vehicle is of similar mass and geometry, it can be seen that occupant safety is often poor, especially in the 'cab-over' construction type that is common in Europe.

This paper presents work carried out by Cranfield Impact Centre Ltd for developing an HGV crash safety standard, based on accident investigations, computer simulations and laboratory cab testing. The work was performed on behalf of the Department for Transport, UK.

ACCIDENT INVESTIGATION

The study of approximately 200 HGV accidents, involving at least one occupant fatality, identified the main accident scenarios and the overall phenomena affecting the cab safety and hence the safety of the occupant. The focus was specifically on the effectiveness of seat belts and cab strengthening in aiding the prevention of fatal and serious injuries to cab occupants.

One critical piece of information recorded during the investigation was the *principal contact surfaces* and *volume penetrations*. This denoted which part

of the surface of the cab was struck as the primary contact area.

The complete volume of the cab, regardless of its size, was divided into a 'grid' of numbered cuboids as shown in Figure 1. Across the width of the cab, the grid divided the cab into three equal parts. In side view, the cab was also divided into three segments of equal width. For cabs that had a sleeper compartment, an additional set of volumes was included, (numbered 55 to 72).

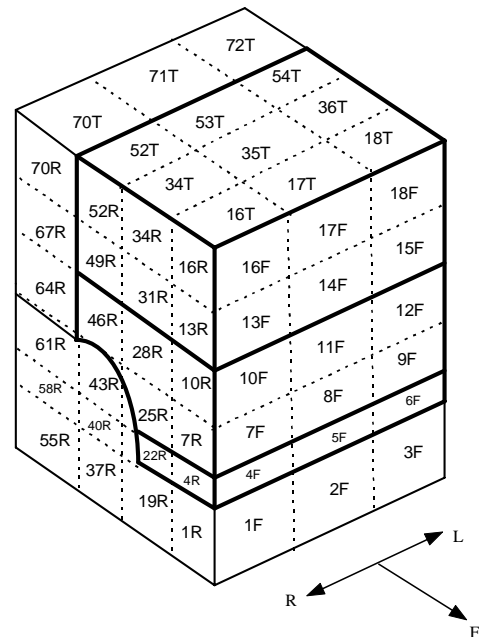


Figure 1. Cab reference system for analysing cab intrusion.

For crashes involving multiple impacts, the combination of photographic and written evidence was used to determine the contact that resulted in the primary cause of injury.

The grid system in Figure 1 was also used to record the amount of deformation of the cab from the photographic evidence and written text.

Another important piece of information recorded was the *effectiveness of fatality reduction measures*. For each accident, an assessment was made of how effective the following measures would have been in reducing the fatal injury to a lesser, survivable level of injury. In view of the essential need to prevent occupant *ejection*, the two measures considered were:-

- Seat belts only
- Seat belts combined with cab strengthening

Across the 200 cases, 4 major accident categories were detected. These were:-

- HGV overturned (63 Cases)
- HGV hit on-coming vehicle (49 Cases)
- HGV hit rear of stationary/slow-moving vehicle (43 Cases)
- HGV ran off road with no rollover (35 Cases)

HGV Overturned Accidents



Figure 2. Typical overturned cab accident.

These constituted the largest accident category with 63 cases. In 38 of these, overturning resulted from the HGV running off the road. It is believed that driver fatigue and falling asleep was significant in this respect. Furthermore, 14 cases of overturning were due to 'dynamic instability' where the HGV toppled-over due to its lack of stability. In 3 cases, overturning was caused by the separation of a road wheel. In 45 out of 63 cases, the HGV rolled onto its side and in 16 cases it rolled onto its roof. Of the 26 cases where the HGV impacted a crash barrier, in 18 of these, the HGV overturned as a result of impacting the barrier. The relation of crash barrier performance to HGV overturning is worthy of further consideration.

There were a total of 67 fatalities from the 63 accident cases in this category. For 22 of these, it could not be estimated whether their death would have been preventable by seat belts alone or by belts plus cab strengthening. Of the remaining 45, it was estimated that 15 (33 %) deaths were preventable, i.e. 12 (27 %) by 3-point belts alone and 3 (7 %) by seat belts and a 'reasonable' cab strengthening.

HGV Impact with On-Coming Vehicle

This formed the second largest category with 49 cases. In 41 cases, the 'other' vehicle that was hit was another HGV. Impact with small vehicles posed no risk to HGV occupants in this study. Of the 49 cases, 31 occurred on rural A-roads where operating speeds were comparatively high and

opposing traffic was not physically segregated. Typical of such cases was where one or other HGV lost control on a bend to some extent and impacted an on-coming HGV. The front or side of the 'other' HGV were the areas that struck the cab of the 'subject' HGV most frequently in this study.



Figure 3. Typical accident involving impact with an on-coming vehicle.

There were a total of 50 fatalities in this category. For 17 of these, it could not be estimated whether their death would have been preventable by seat belts alone or by belts plus cab strengthening. Of the remaining 33, it was estimated that 14 (42 %) deaths were preventable, i.e. 10 (30 %) by 3-point seat belts alone and 4 (12 %) by seat belts and a 'reasonable' cab strengthening.

HGV Impact with Rear of Stationary/Slow-Moving Vehicle



Figure 4. Typical accident involving impact with the rear of a stationary vehicle.

Although this formed the third largest category in this study, with 43 cases, there was a greater similarity between the accidents in this category than in any other. It therefore constituted the most significant category, in the sense of relating to one specific accident type. Of the 43 accidents, 42 involved the HGV hitting the rear of another HGV. These accidents happened predominantly on

motorways and dual carriageways (36 cases). In 41 cases, the HGV which was hit, was either stationary (on the hard-shoulder or in a traffic queue - 29 cases), or was slow-moving (due to being a heavy-load or on an incline - 12 cases). The rear of a rigid or articulated HGV load platform, in its various loaded and unloaded states, presented a rigid surface which often intruded severely through the sheet metal and windscreen of the impacting HGV.

There were a total of 43 fatalities in this category. For 12 of these, it could not be estimated whether their death would have been preventable by seat belts alone or by belts plus cab strengthening. Of the remaining 31, it was estimated that 14 (45 %) deaths were preventable, i.e. 8 (26 %) by 3-point seat belts alone and 6 (19 %) by seat belts and a 'reasonable' cab strengthening.

HGV Ran Off Road with No Overturning

There were 35 cases where the HGV left the carriageway without overturning. This category covered a number of different outcomes and contained the most disparate range of accidents of the four major categories. Objects struck included falls from bridges (6 cases), trees (5 cases), low walls (5 cases) and others. The common factor in this category was that the vehicle did not overturn. The largest sub-group in this category was impacts with concrete bridge supports and other vertical stanchions, located on the central reservation and side verge of motorways and dual carriageways. With regard to these latter impacts, it was seen on several occasions, that an HGV, which had initially impacted a crash barrier, would be entangled and guided into a more serious impact with a bridge support. Predominantly, the category 'ran off road' accidents took place on high speed roads such as motorways and dual carriageways.

There were a total of 35 fatalities in this category. For 8 of these, it could not be estimated whether their death would have been preventable by seat belts or by belts alone plus cab strengthening. Of the remaining 27, it was estimated that 13 (48 %) deaths were preventable, all by seat belts alone. In the sample considered it did not appear that a 'reasonable' cab strengthening would have helped.

DEVELOPMENT OF A CAB STANDARD

From the accident investigation carried out, the following generic accident types were defined: *offset frontal impact, full frontal impact and 180° and 90° rollover*. These were simplified into the following two categories for which the new cab standard would address:-

- Rollover
- Frontal Impact

Rollover

Finite Element (FE) Simulations

FE computer simulations were carried out for a 'gentle' 180° rollover (ie. down a 45° slope) shown below in Figure 5. The magnitude of the cant-rail load and manner of cab deformation were shown to vary during the rollover phase. The recommended Type Approval test conditions were determined at the time of peak load.

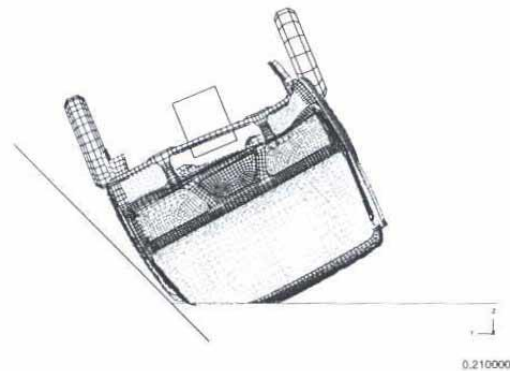


Figure 5. Typical rollover accident simulation.

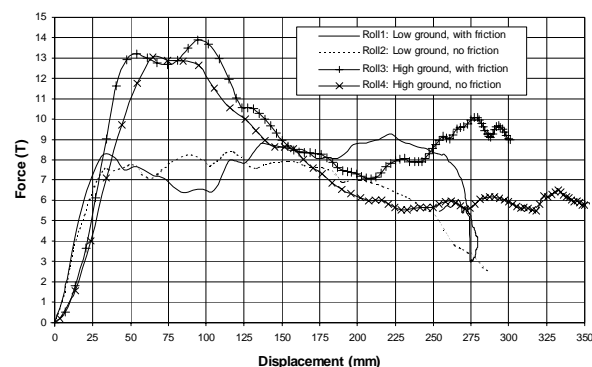


Figure 6. Cant-rail loads v displacement towards survival space for 4 different rollover accident simulations.

Recommended Type Approval Test to Represent Rollover Accidents

The proposal of the roof crush Type Approval test consists of the following:-

- (a) Concentrates on the intermediate phase during rollover down an embankment and argues that the most dangerous loading occurs in the later stages of the 180° roll (which was substantiated by simulation) with the momentum rolling the vehicle 'gently' through 180° and 'lifting' the mass after the initial ground contact, thus reducing the ground reaction in comparison with the state when the mass 'comes down again', at roll angles between 135° and 180°.

- (b) Proposes that the cab be mounted on the chassis which is rigidly attached to the test bed; the cab is tilted through 25° (driver's side up) about its longitudinal axis and loaded statically by a large flat, horizontal platen (Figure 7). The friction between the cant-rail and platen needs to be minimised.

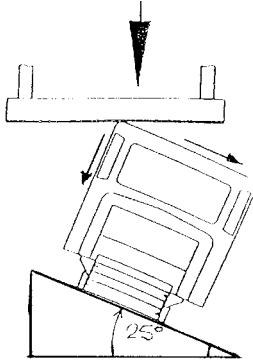


Figure 7. Proposed roof crush test loading.

- (c) The requirement is defined in terms of the maximum oblique load that the cab must resist without intruding into the residual space defined by a seated 'driver', i.e. a 95 %ile dummy or an appropriate volume contour.
- (d) The maximum test force represents a factorised front unladen axle load of the heaviest vehicle for which the cab is intended (an upper limit is set in the case of multi-axle tractor units). The unladen axle load is taken as reference because:-
- d1 : the cargo is likely to become detached from the vehicle in a rollover and act in a 'self-arresting' mode,
 - d2 : the rear end of the vehicle will also 'self-arrest'.

The factor multiplying the front axle weight was determined from the rollover simulation where a peak load of 10.9 tonnes was generated on the cant-rail when using a front axle weight of 3.5 tonnes.

However, the FE model was shown to be over-stiff when comparing the peak loads for the roof crush simulation (8.1 tonnes) and roof crush test (7.2 tonnes). Therefore, a factor of $7.2/8.1 = 0.88$ was applied to the peak load during the rollover simulation, in order to more accurately predict the peak load generated during an actual rollover.

Adjusted peak load during rollover simulation = $0.88 \times 10.9 = 9.6$ tonnes.

Factor = $9.6 / 3.5 = 2.7$

Therefore,

Max. Load = $2.7 \times$ Unladen Front Axle Weight
(limit = 100kN)

Roof crush tests

Two roof crush tests were carried out using the conditions outlined in the previous section. The first test was performed on an all-steel cab (Figures 8 and 9).

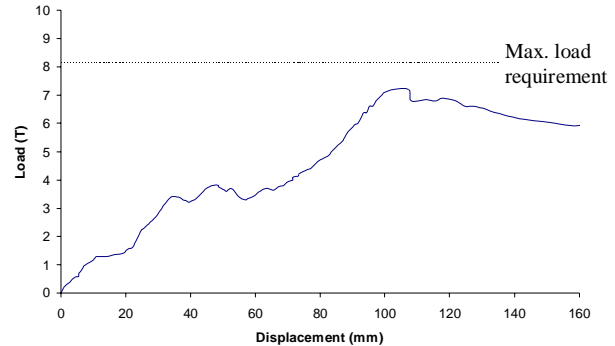


Figure 8. Load v displacement results for all-steel cab (failed).



Figure 9. Permanent deformation of all-steel cab after roof crush test (picture shows cab ready for frontal impact test).

The second test was performed on a slightly larger cab constructed using glass fibre composite panels mounted onto a steel sub-frame (Figures 10 & 11).

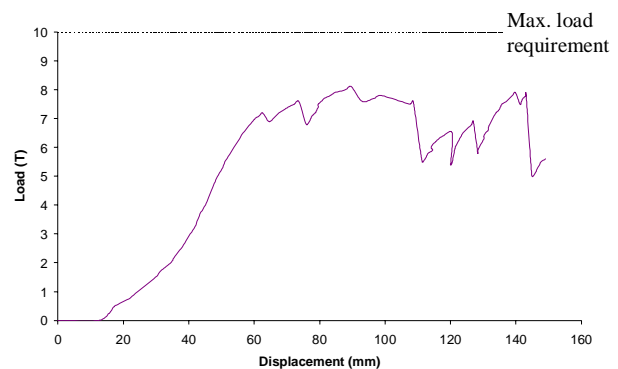


Figure 10. Load v displacement results for steel/composite cab (failed).



Figure 11. Deformation of steel/composite cab during roof crush test.

The maximum load requirement for each cab is shown as the horizontal dotted line on the displacement graphs. The graphs show that both cabs fall below the proposed standard for the oblique roof crush.

Frontal Impact

Finite Element (FE) simulations

FE computer simulations were carried out for 12 different **frontal impact accident scenarios**. The FE model used for these simulations is shown in Figure 12.

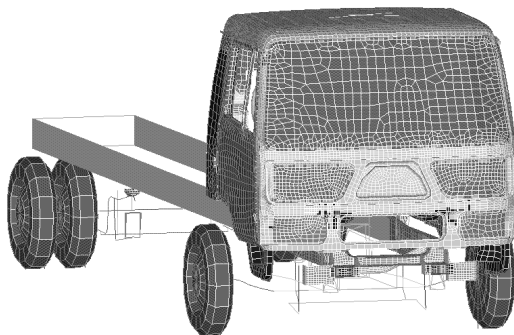


Figure 12. Detailed FE model of HGV for frontal impact accident simulations.

The cab was attached to the chassis via two front and two rear mounts, which were modelled as rigid and non-failing.

A 12 tonne truck with initial velocity of 22mph was simulated. This represented an initial KE equal to 600kJ.

A rigid, 95%ile Hybrid III dummy was seated on the impacted side of the cab and positioned with knees and hips 100mm forward and chest 200mm forward of the normal seated position. The dummy was used to gauge the extent of driver intrusion whilst in a forward position relating to that of a 3-point belted dummy subjected to a typical frontal impact. The dummy did not interact with the

deforming cab structure and so did not influence the extent of deformation.

The simulations varied the following parameters:-

- Rigid/rolling barriers
- 100% and 50% overlap
- High/low barriers
- Deformable barrier sections to represent underrun guards and chassis rail interactions
- Barrier overhang
- Material properties of steel cab

A typical frontal impact simulation is shown in Figure 13. The truck model impacts a simplified model of the rear end of another truck of the same mass, which is free to move upon impact.

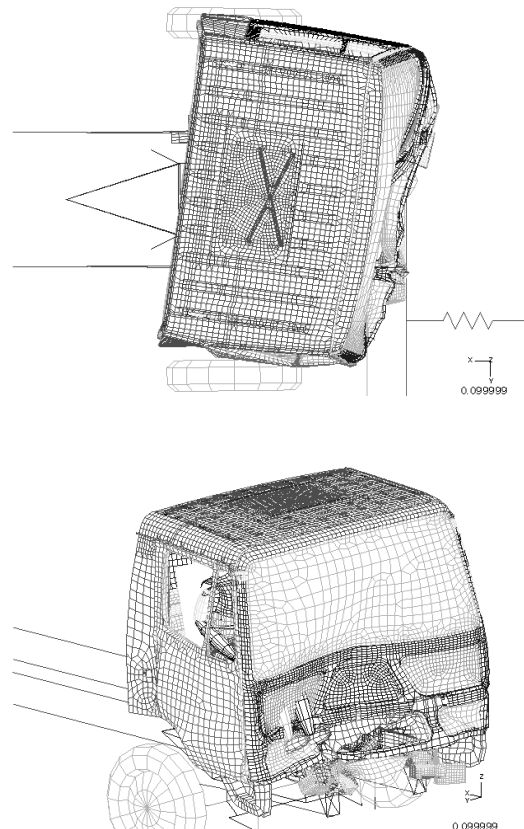


Figure 13. Deformed shape of typical frontal impact accident simulation.

The 95%ile Hybrid III dummy was rigidly positioned in the driver's seat. No contact definitions were defined between the dummy and cab, allowing the extent of driver intrusion to be visually monitored.

Figure 14 shows the time history plots for the internal energy absorbed by the impacting vehicle. The plot shows the total energy absorbed by the vehicle and also the proportion of energy absorbed by the chassis and the cab.

The amount of energy absorbed by the cab was used to help determine the magnitude of the impact energy used in the recommended Type Approval test.

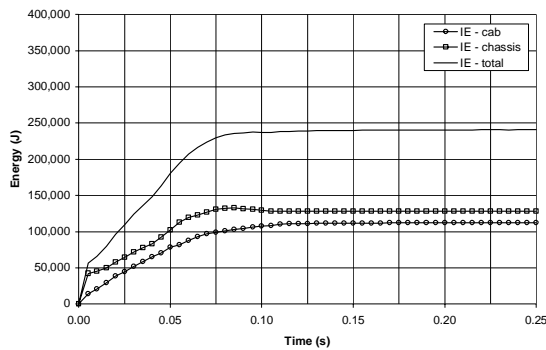


Figure 14. Energy time history for above frontal impact accident.

Simulations were also carried out for 13 possible **testing configurations** in order to predict the cab performance and determine which configuration was most suitable for a Type Approval test.

One important aspect of the Type Approval test was the shape of the pendulum impactor – cylindrical or flat? (Figures 15 and 16).

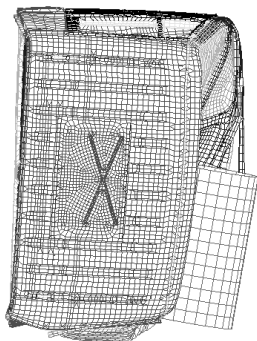


Figure 15. Cylindrical impactor.

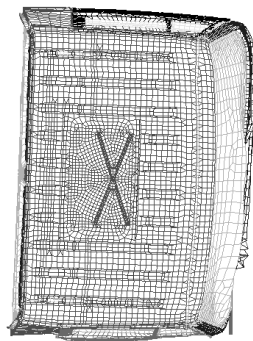


Figure 16. Flat impactor.

The flat impactor distributes the impact load over a larger area of the cab and is therefore less aggressive to the cab structure.

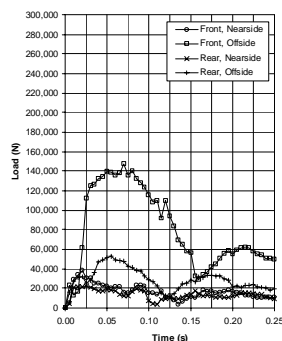


Fig 17. Cab mount loads for cylindrical impactor.

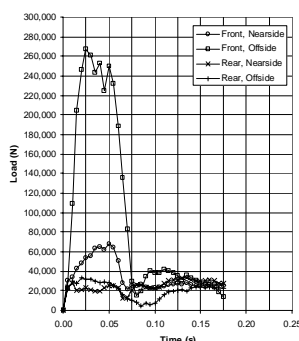


Fig 18. Cab mount loads for flat impactor.

However, it loses its kinetic energy more rapidly than the cylinder and hence creates relatively high loads at the cab-to-chassis mounts (Figs 17 & 18).

The aim of a Type Approval test was to reproduce the required cab deformation (and hence driver intrusion), using the safest and therefore lowest energy option. Also, the cab mounts are not as important as the cab structure for protecting the driver and so the test should not load these components excessively.

The final reason for choosing a cylindrical pendulum was to comply with existing test rigs in Europe, of which the chain hung cylinders are relatively common.

Both sets of simulations (accident and test) were *critical in the quantification of the impact energy* to be used in the recommended Type Approval test.

Recommended Type Approval Test to Represent Frontal Impact Accidents

The recommended test represents the offset frontal impact into the rear of another HGV. The test was proven (by simulation) to be the worst case scenario and hence covered full frontal impacts also.

The dynamic impact test consisted of a 1 tonne cylindrical pendulum impactor (chain hung), striking perpendicular to the front of the cab at a 50% offset. The residual space to be left intact was again the 95%ile Hybrid III dummy. The energy of impact = 40kJ.

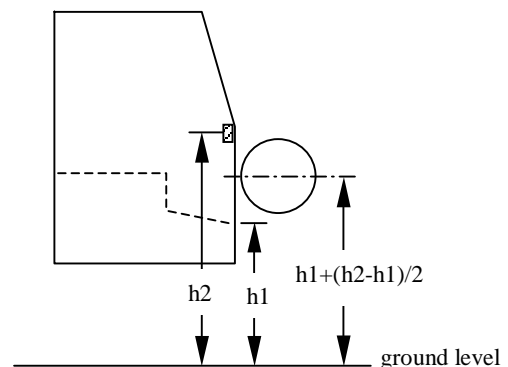
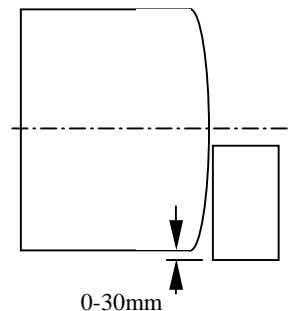


Figure 19. Proposed frontal impact test.

Frontal impact tests

Six frontal impact tests were carried out on various cab types, using the conditions outlined in the previous section. However, the impact energy ranged from 20 to 40kJ. The energy was adjusted for each particular cab due to the following reasons:-

- some of the cabs had already sustained damage from having been roof crushed
- incremental impacts were used when the strength of the cab and mounts were difficult to predict

The cabs tested included the following construction types:-

- All steel
- Steel/composite
- All composite

Cab strengthening measures were recommended due to the initially poor performance of the all steel 'walkthrough' cab type (Figures 20 and 21). The modifications included reinforcements to the front panel, door, B-pillar, and mounts, and were designed in a commercially feasible manner.



Figure 20. All-steel cab, rigid mounts, 20kJ.



Figure 21. All-steel cab, original mounts, 38kJ.



Figure 22. All-steel cab, with strengthening modifications, 40kJ.

The testing phase showed that the cab strengthening methods significantly improved the cab performance with regard to frontal impacts (Figure 22).

CONCLUSIONS

Accident investigations showed that a reasonable increase in cab strength combined with wearing a 3-point seat belt would substantially reduced the number of HGV fatalities.

Type Approval test conditions have been successfully developed through a procedure of accident investigations, computer simulations and laboratory cab testing. The loading in the roof crush test and energy in the frontal impact test have both been evaluated through reasoned methods, giving a high degree of confidence in their representation of actual accident phenomena.

The cab standard for **rollover** accident scenarios consists of a quasi-static roof crush test at an angle of 25° to the horizontal. The cab must reach a maximum load equal to 2.7 times the unladen front axle weight of the vehicle before the residual space defined by a 95%ile dummy template is intruded upon. A maximum load of 10 tonnes has been imposed.

The cab standard for **frontal impact** accident scenarios consists of a dynamic 50% offset impact test using a chain hung cylindrical pendulum. The impact energy is 40kJ (pendulum mass equal to 1-1.5 tonnes) and the residual space, not to be intruded upon, is a seated 95%ile dummy template.

The roof crush and frontal impact tests outlined above, are proposed for future HGV cab safety standards.

Simple cab strengthening modifications were shown to be sufficient to bring a sub-standard HGV cab up to the required standard.